FLIGHT SIMULATOR EXPERIMENTS TO DETERMINE HUMAN REACTION TO AIRCRAFT MOTION ENVIRONMENTS

Annual Status Report
Grant No. NGR 47-005-202

Submitted to:

National Aeronautics and Space Administration
Scientific and Technical Information Facility
P.O. Box 33
College Park, Maryland 20740

Submitted by:

Ira D. Jacobson

and

Ashok N. Rudrapatna

RESEARCH LABORATORIES FOR

THE ENGINEERING SCIENCES

SCHOOL OF ENGINEERING AND APPLIED SCIENCE

UNIVERSITY OF VIRGINIA

CHARLOTTESVILLE

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#1

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Short-Haul Air Transportation Program

Memorandum Report 403902

DEPARTMENT OF ENGINEERING SCIENCE AND SYSTEMS
RESEARCH LABORATORIES FOR THE ENGINEERING SCIENCES
SCHOOL OF ENGINEERING AND APPLIED SCIENCE
UNIVERSITY OF VIRGINIA
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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

INTRODUCTION

This report presents an analysis of human response to aircraft motion using data obtained on the NASA Flight Research Center's Jetstar aircraft. The purpose of these tests was to explore the relationship of vertical and transverse accelerations to human comfort as well as obtain information on the maximum comfortable bank angle for commercial aircraft operations. A preliminary study was also conducted to establish the importance or lack thereof of the low frequency content of aircraft motion due to natural turbulence. An effort has been made to "model" these data and comparisons with appropriate sources are made.

In addition to augmenting the existing data base for human response, this study has provided information currently not available in two areas. First, the use of the Jetstar GPAS (General Purpose Airborne Simulator) system has made it possible to obtain human responses to accelerations beyond what is currently found in today's aircraft, and important for future aircraft designs (e.g., STOL and RTOL). Second, a knowledge of the effects of frequency spectrum will be invaluable in determining the applicability of ground-based simulator data needed to study the basic theory of human response.

EXPERIMENT DESCRIPTION

The basic aircraft, shown in Figure 1, is a Lockheed JetStar modified to carry the GPAS system. In addition to the "normal" control surfaces, the aircraft is equipped with direct lift flap control (dlc) surfaces and side force generator (sfg) surfaces. The use of these surfaces for the current study allow a wide range of vertical and transverse accelerations to be obtained.

A typical flight is shown in Figure 2 where a segment consists of a predetermined motion signature for a duration of 1 minute--runs 1 and 3 are used to evaluate vertical and transverse accelerations while runs 2, 4, and 5 indicate the effects of turns. Runs 1, 2, and 3 were constant altitude (20,000 feet) and runs 4 and 5 were descending turns. The elapsed time from take-off to landing is 60 minutes. In addition to the flight engineer, pilot and copilot, two subjects who continuously indicated their comfort were on board. A five-point comfort scale was used with the following designations:

1 - Very comfortable

2 - Comfortable

3 - Neutral

4 - Uncomfortable

5 - Very uncomfortable.

Each subject was given instructions on the use of the comfort scale prior to flight. The responses were automatically recorded along with the aircraft's motion variables.

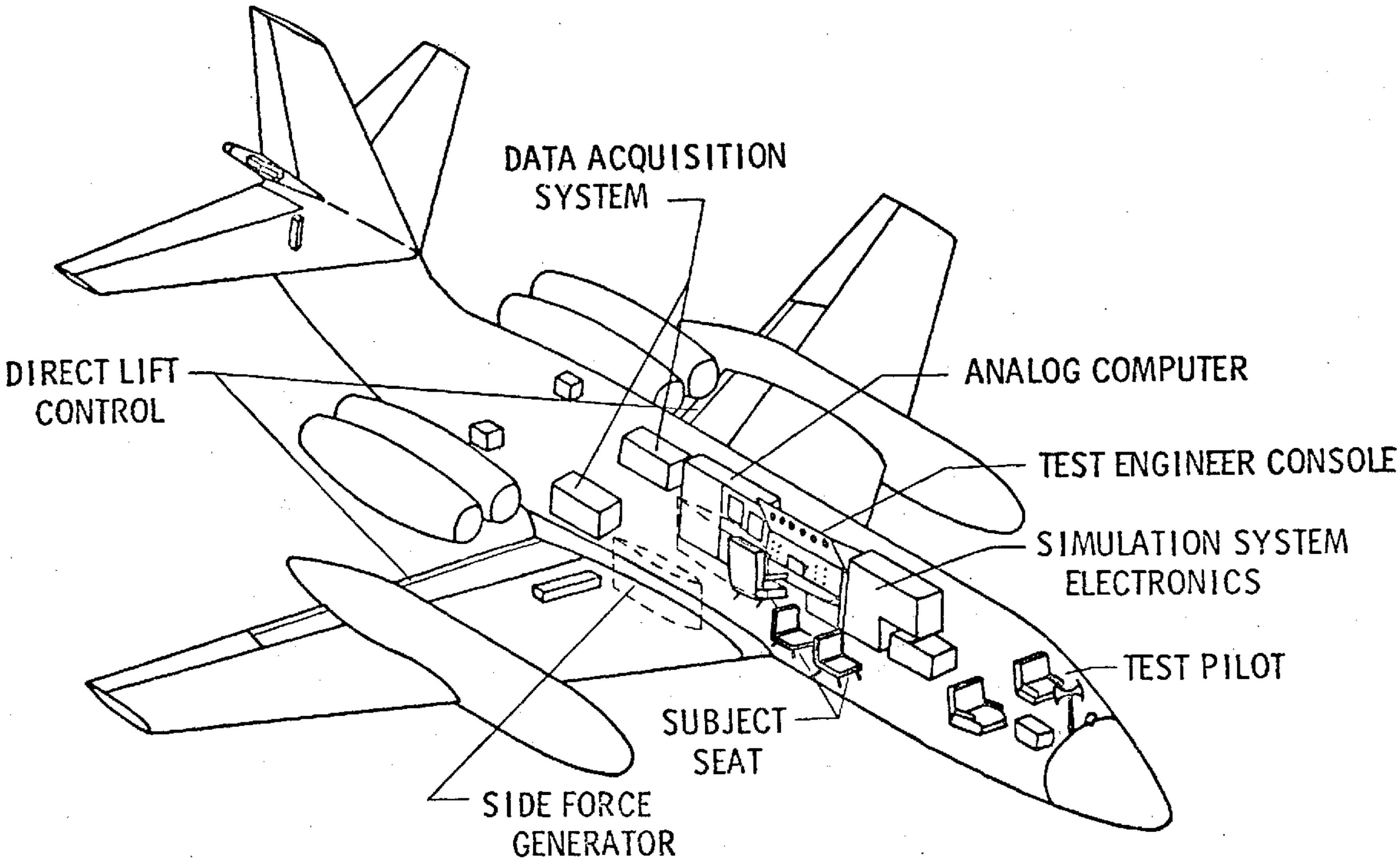

FIGURE 1. NASA GENERAL PURPOSE AIRBORNE SIMULATOR (GPAS)

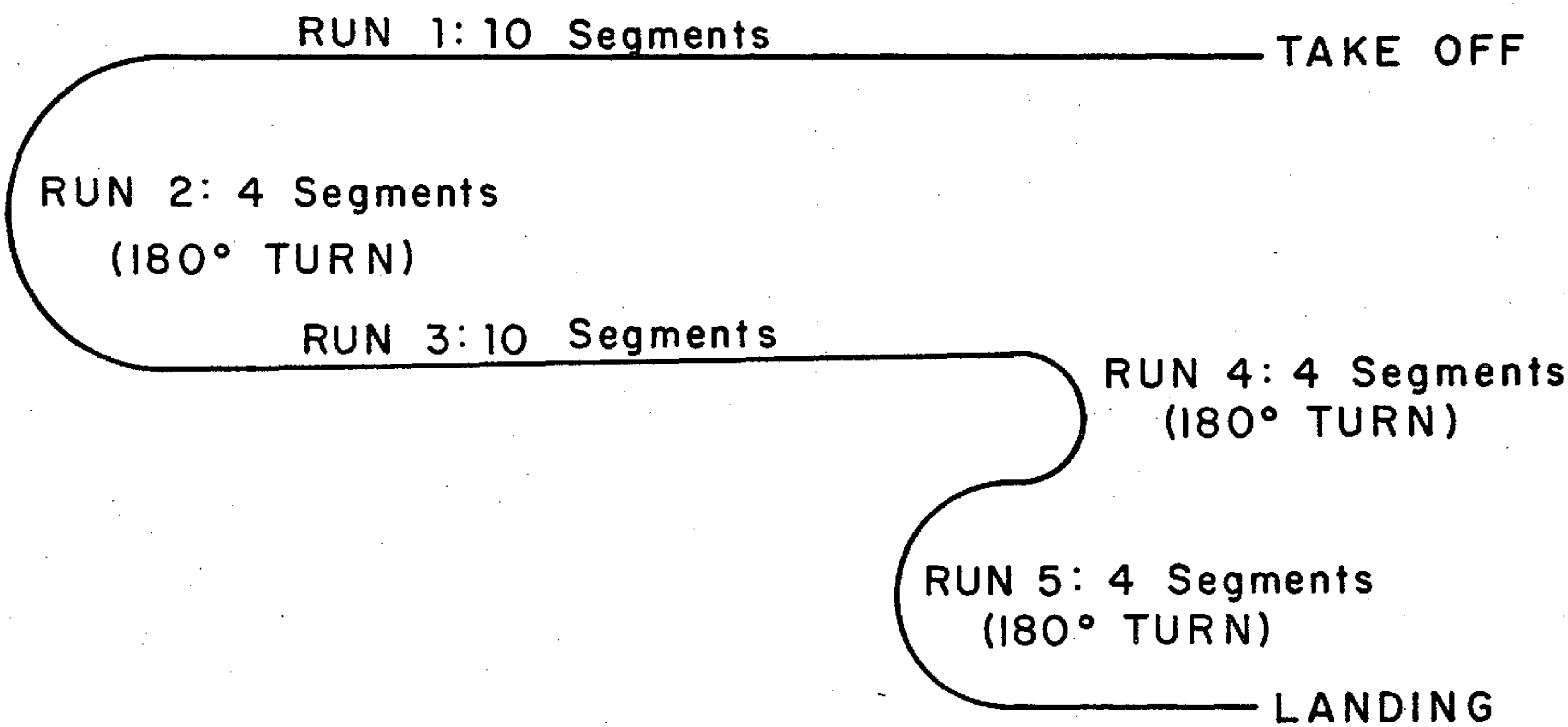

FIGURE 2. TYPICAL FLIGHT PATTERN

SUBJECT PROFILES

The 25 subjects used in this experiment ranged in age from 20 to 55 with 30 percent being women. Their previous flying experience and occupational backgrounds are shown in Figures 3a and 3b. Forty-seven percent fly 1-3 times/year while 53% fly over 3 times/year. In terms of attitude toward flying, a large percentage--68%--indicated they love flying. This compares with 45% of the general commercial air passengers who like to fly.[1]

DATA REDUCTION

The data was digitally recorded in-flight and later reduced using standard numerical techniques on the NASA FRC Cyber-70 computer system. In addition to mean values and standard deviations of aircraft motion variables, representative power spectra were obtained. The data include all six degrees of freedom of motion with linear accelerations at two fuselage locations and both angular accelerations and rates at the aircraft center of gravity obtained.

DATA ANALYSIS

Acceleration Data

Wide coverage of the acceleration variables was obtained (Figure 4) yielding a large data base for the development of a model of human response

PILOT	PRIVATE A/C PASSENGER	COMMERCIAL PASSENGER
21%	79 %	100 %

FIGURE 3a. PREVIOUS EXPERIENCE

PROFESSIONAL	58%
SECRETARY	21 %
TECHNICIAN	21 %

FIGURE 3b. OCCUPATION

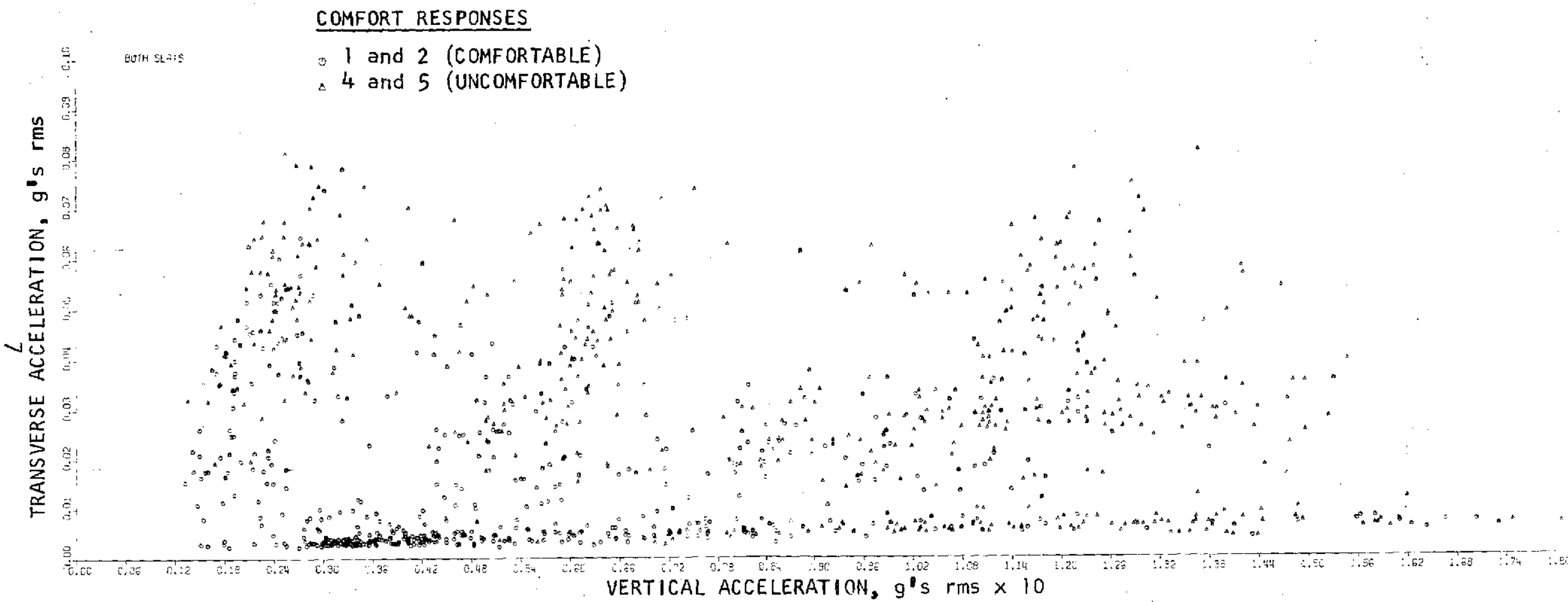

FIGURE 4. JETSTAR FLIGHT DATA (GPAS SYSTEM)

to comfort. In this figure, the triangles represent uncomfortable ratings while the circles represent comfortable ratings. Neutral ratings are omitted for clarity. The ability to obtain data in the high transverse/low vertical acceleration range is important for future aircraft configurations and these data represent the first flight data in this area.

Figures 5 through 7 summarize these data. Figures 5 and 6 indicate the variation in the average rms vertical and lateral accelerations for each of the comfort ratings shown, respectively. The vertical acceleration data are compared with that obtained during commercial flights[2],[3],[4],[5] where it can be seen that for ratings toward the uncomfortable end there is general agreement; however, the subjects used in this experiment remained more comfortable for higher levels of acceleration than the commercial data indicates. Also, it is clear that it requires less transverse acceleration to elicit equivalent responses. Figure 7 indicates the effect of combining the accelerations--iso-contours indicate the boundaries of equivalent comfort. These curves represent the average value of accelerations for the specified comfort response.

A straightforward regression analysis on these data yields the curve shown in Figure 8. Here the data have been subdivided into two regions to allow the incorporation of previous results[5], including passenger satisfaction comparisons.

Spectral Effects

In order to determine spectral effects, three spectra for the aircraft motion were examined. These are shown in Figures 9a and 9b for arbitrary rms values.* As can be seen the simulated spectra for atmospheric turbulence agree well with natural turbulence. These tests were conducted using four

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*Amplitudes were adjusted to maintain equivalent total rms without altering the spectral shape.

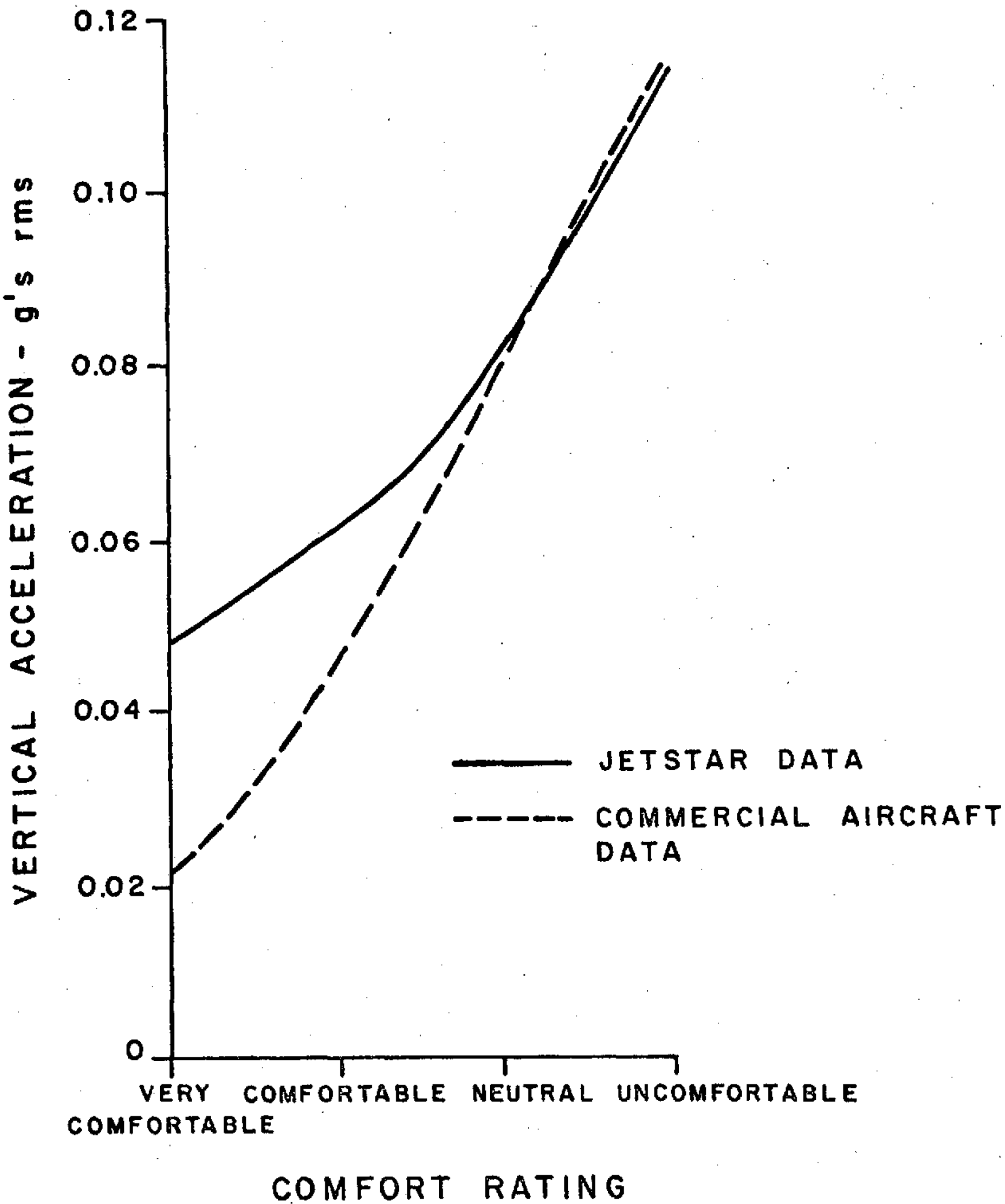

FIGURE 5. AVERAGE VERTICAL ACCELERATION VS. COMFORT LEVEL
(Transverse Acceleration <.016 g's rms)

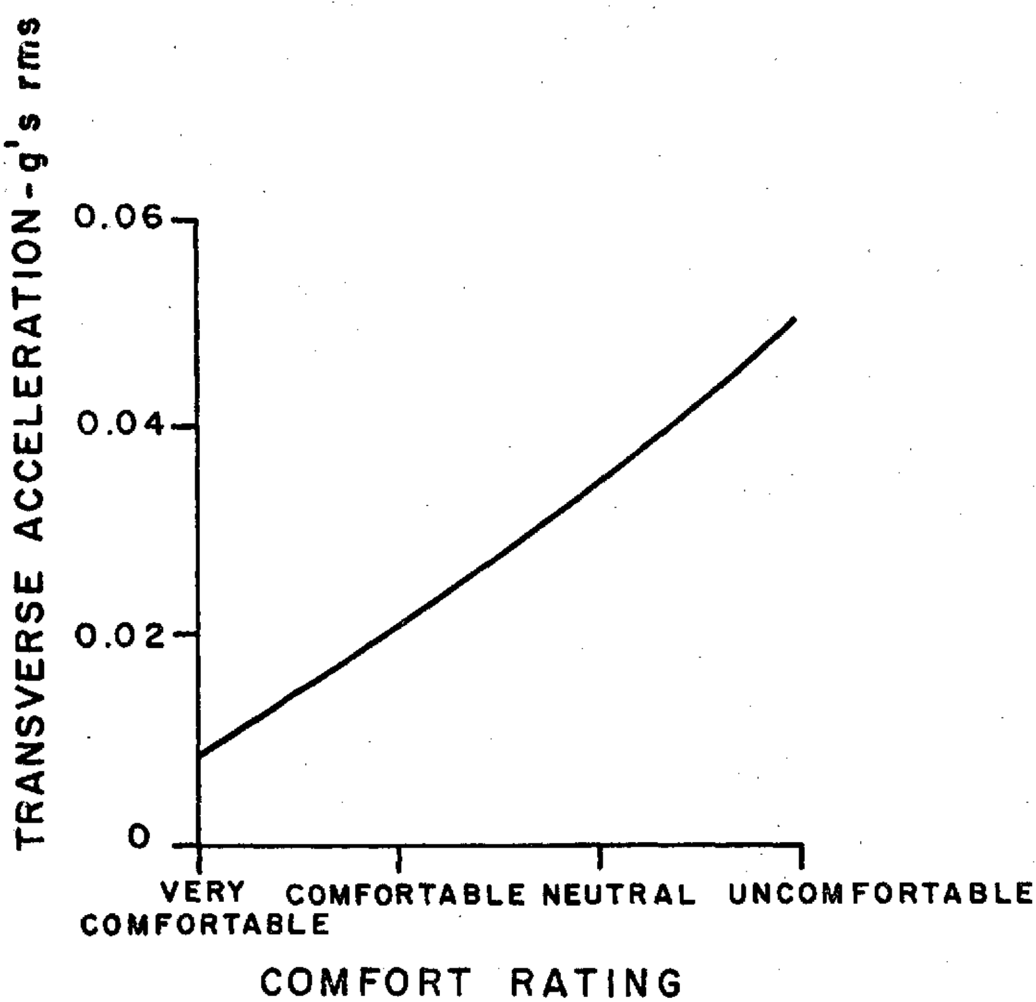

FIGURE 6. AVERAGE TRANSVERSE ACCELERATION VS. COMFORT LEVEL
(Vertical Acceleration < 0.036 g's rms)

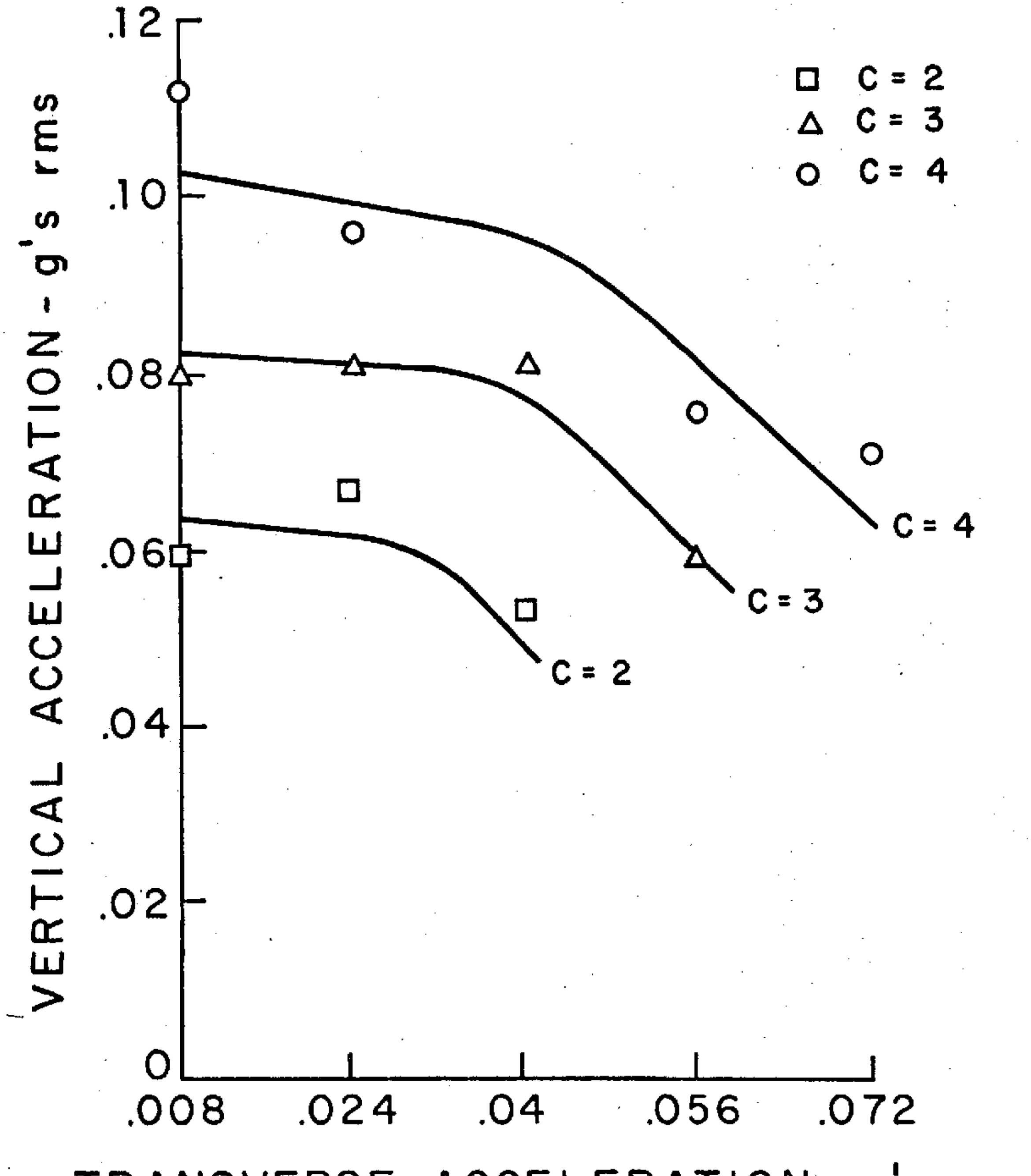

FIGURE 7. COMFORT ISO-CONTOURS

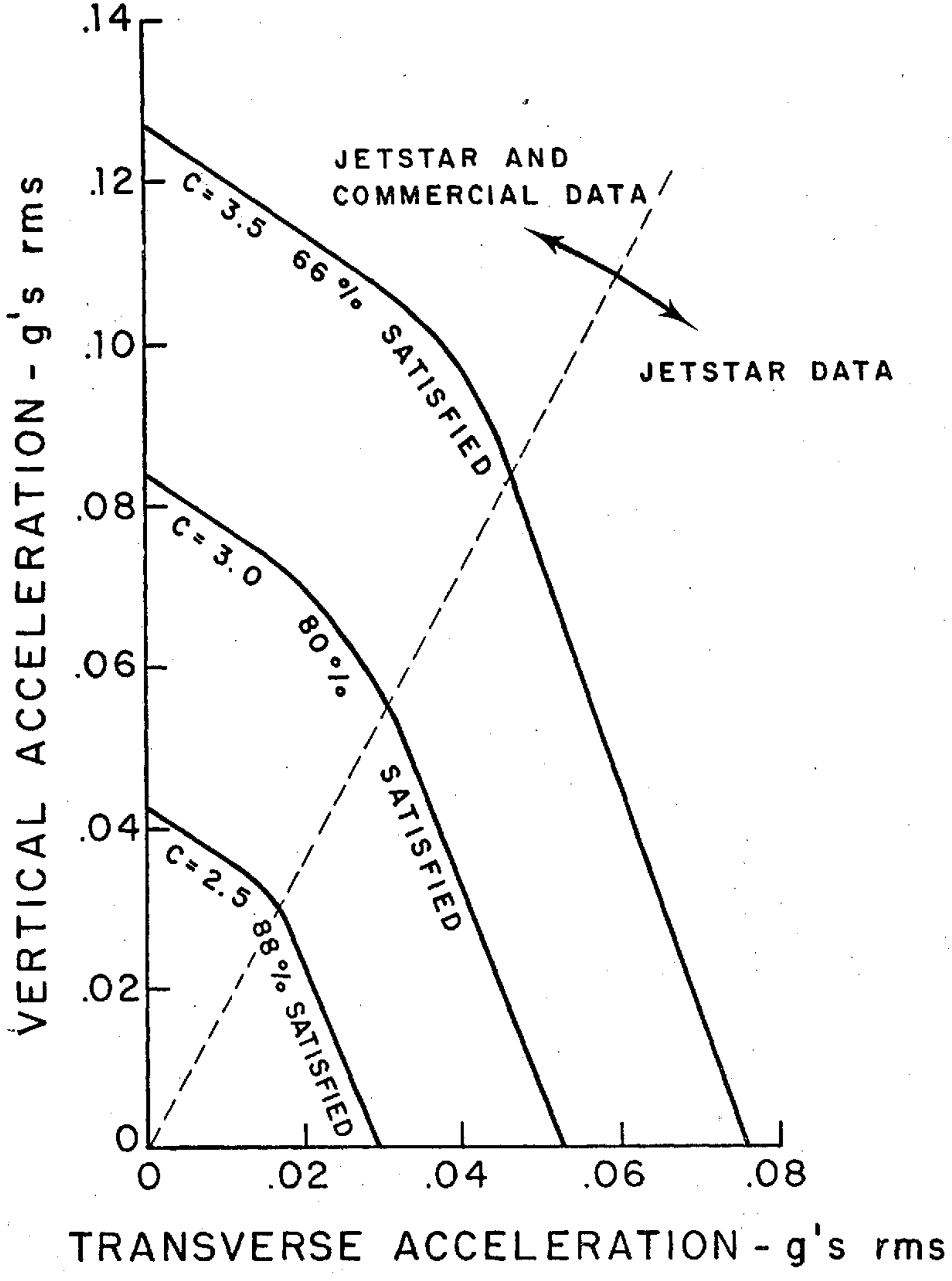

FIGURE 8. REGRESSION LINES FOR ISO-CONTOURS

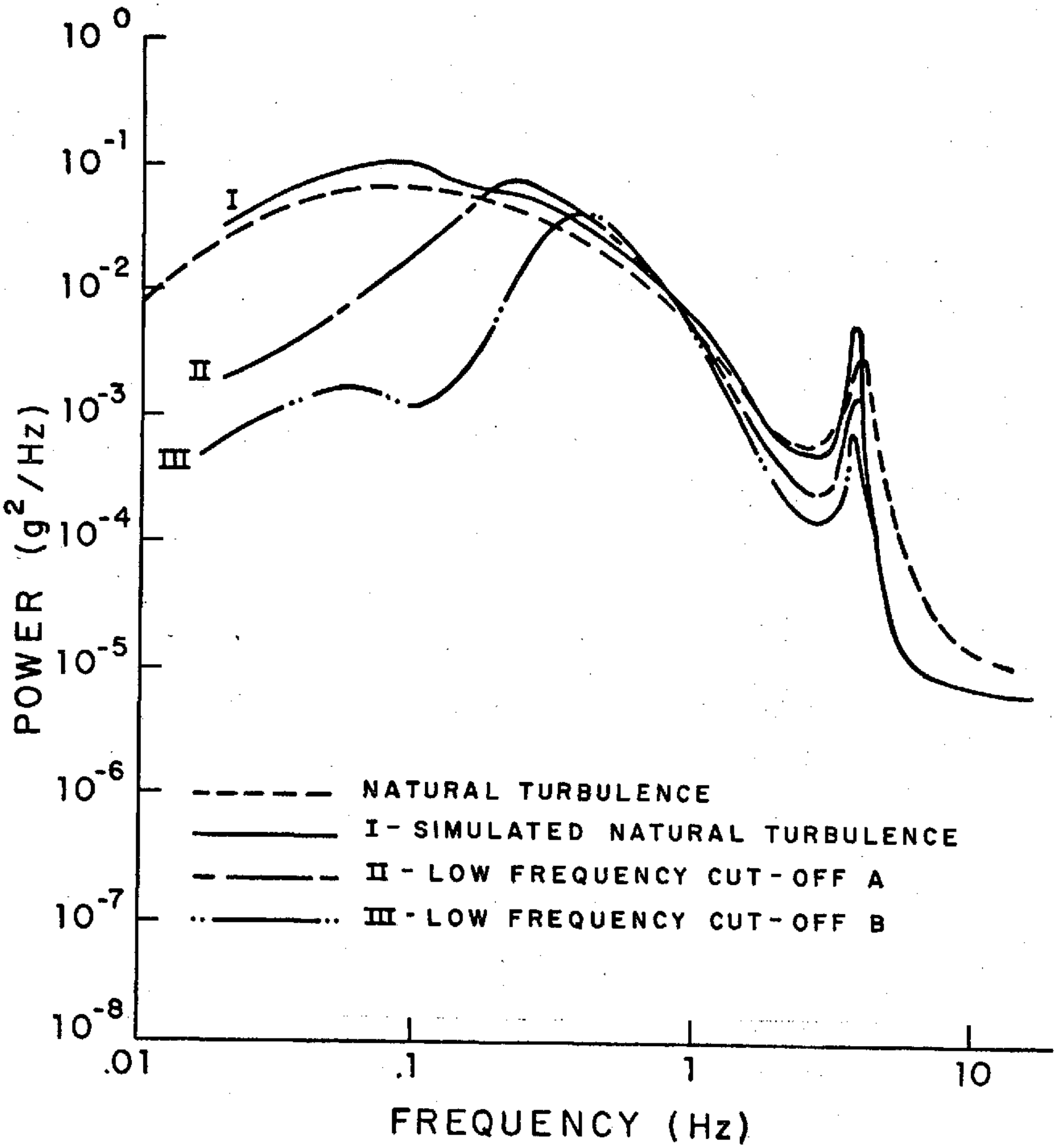

FIGURE 9a. VERTICAL ACCELERATION POWER SPECTRA

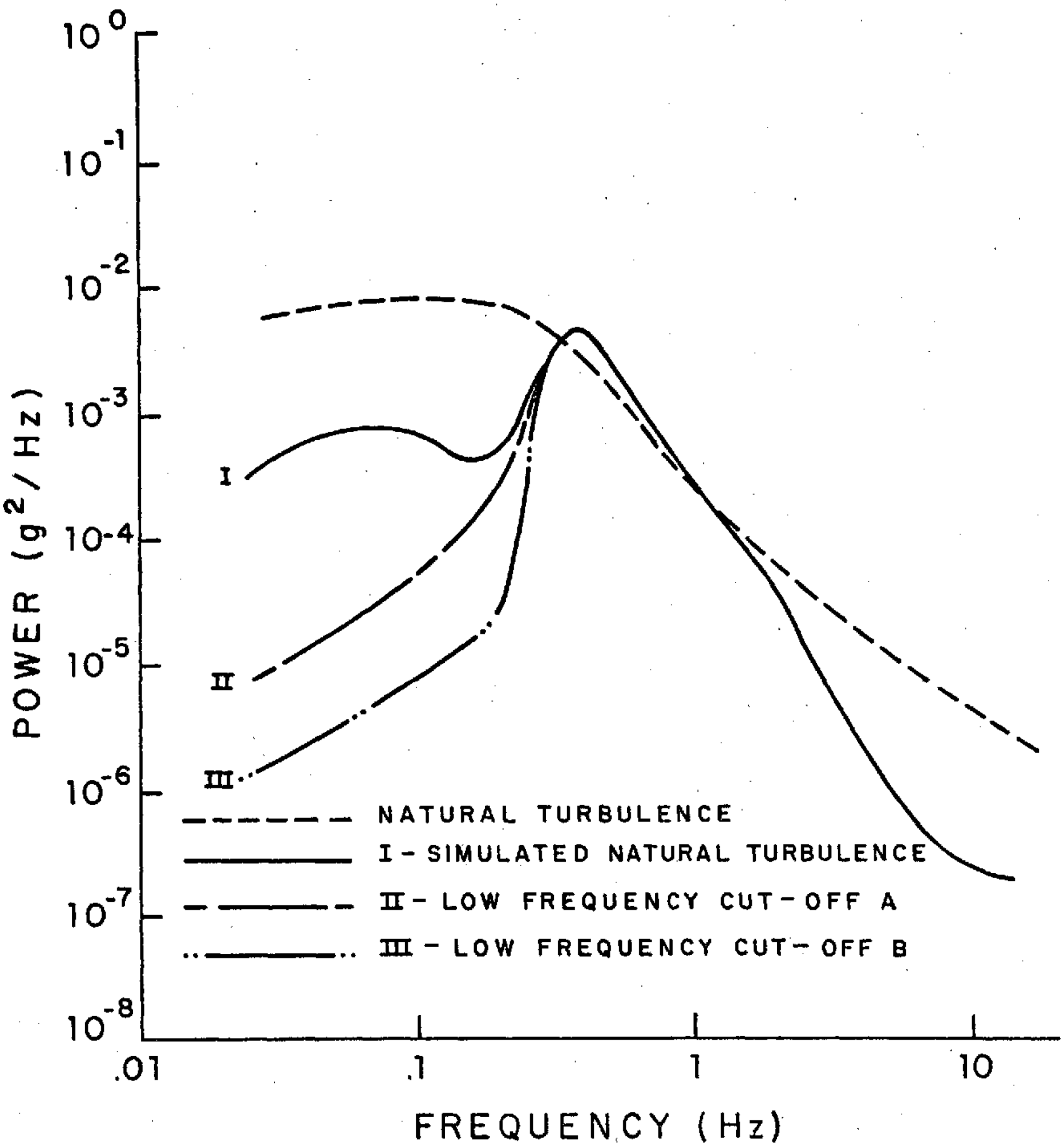

FIGURE 9b. TRANSVERSE ACCELERATION POWER SPECTRA

test subjects over six flights, two flights for each of the spectral types. In these tests, the vertical acceleration was varied for both 0 and 0.02 "g" constant lateral acceleration. The data were analyzed both graphically and statistically--details of which can be found in reference 6. The results of the graphical analysis are given in Table I. Statistically, the hypothesis, H_1, was tested where H is stated as follows:

> H_1: at a given acceleration level, the mean response on flights using spectrum I is .5 greater than the mean response on flights using spectra II or III. (This implies that spectrum I is at least .5 less comfortable than spectra II or III. The consequence of H_1 being true is the necessity of doing tests with an atmospheric spectrum.)

The test is arranged in this way in order to make the most costly error (using spectra II or III for simulations, when in fact they are not suitable) a Type I error (rejecting a true hypothesis).

The results show that in all but three cases the hypothesis H_1 can be rejected at the .1 significance level or lower. This means that there is a 10% chance of H_1 being true. Consequently, we can be 90% confident that the hypothesis is false or that there is not a significant difference in the responses for any of the three spectra. Thus, it can be preliminarily concluded that spectral effects are minimal.

Threshold Comfort

Figures 10 and 11 indicate the "best fit line" of comfort rating versus the log of acceleration in the vertical and transverse directions, respectively. The log was chosen since a number of models[7] (especially psychophysical) use the log of the stimulus (acceleration) to relate to

TABLE I

ACCELERATION LEVELS

(all values in "g" rms)

Response Category			Frequency Spectra I	II	III
	≤2	(Comfortable)	<.025	<.015	<.04
No	2-3	(Uncertainty Region)	.025→.045	.015→.04	.04 →.045
Lateral	3	(Neutral)	.045→.11	.04 →.10	.045→.09
Acceleration	3-4	(Uncertainty Region)	.11 →.13	.10 →.13	.09 →.115
	4	(Uncomfortable)	>.13	>.13	>.115
	2	(Comfortable)	--	--	--
Constant	2-3	(Uncertainty Region)	<.045	<.045	<.05
Lateral	3	(Neutral)	.045→.095	.045→.085	.05 →.065
Acceleration	3-4	(Uncertainty Region)	.095→.13	.085→.125	.065→.105
	4	(Uncomfortable)	>.13	>.125	>.12

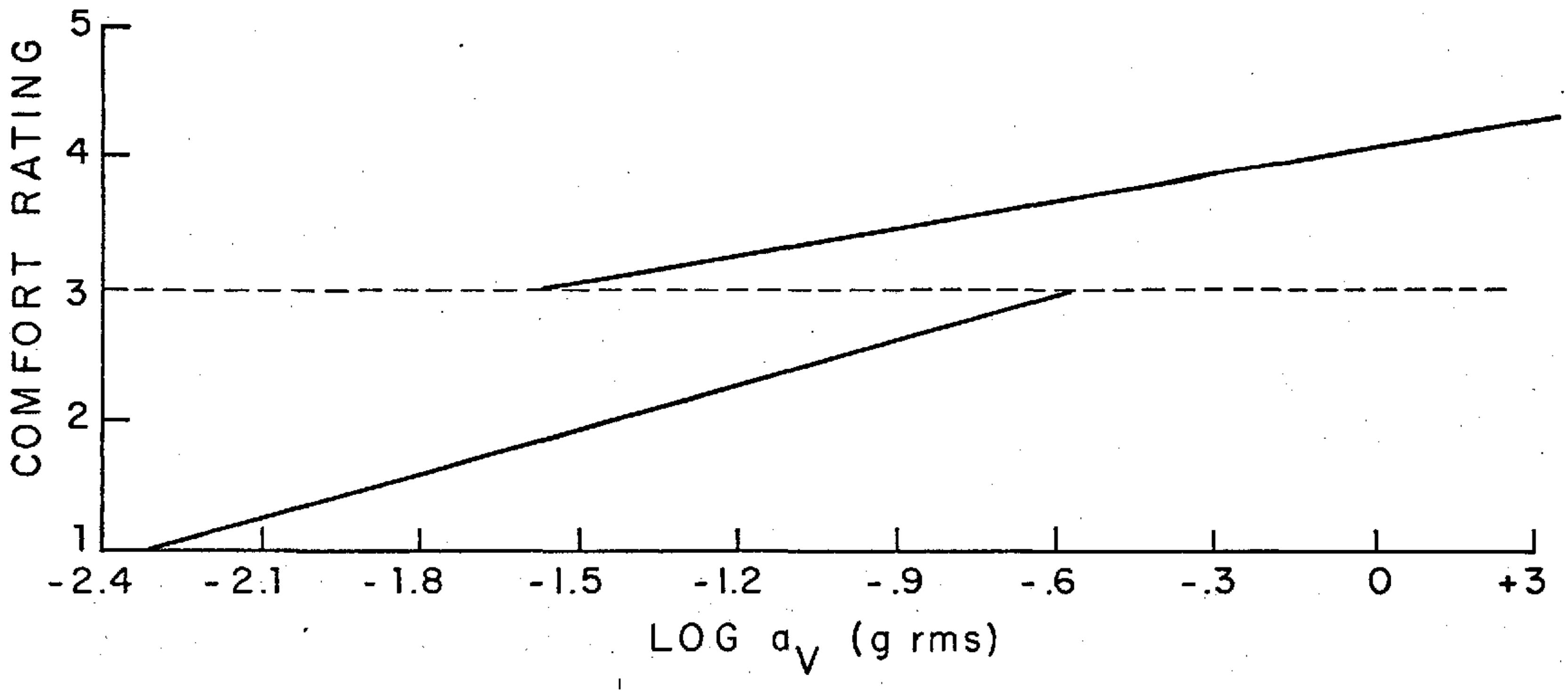

FIGURE 10. REGRESSION LINE OF COMFORT VS. LOG (VERTICAL ACCELERATION)

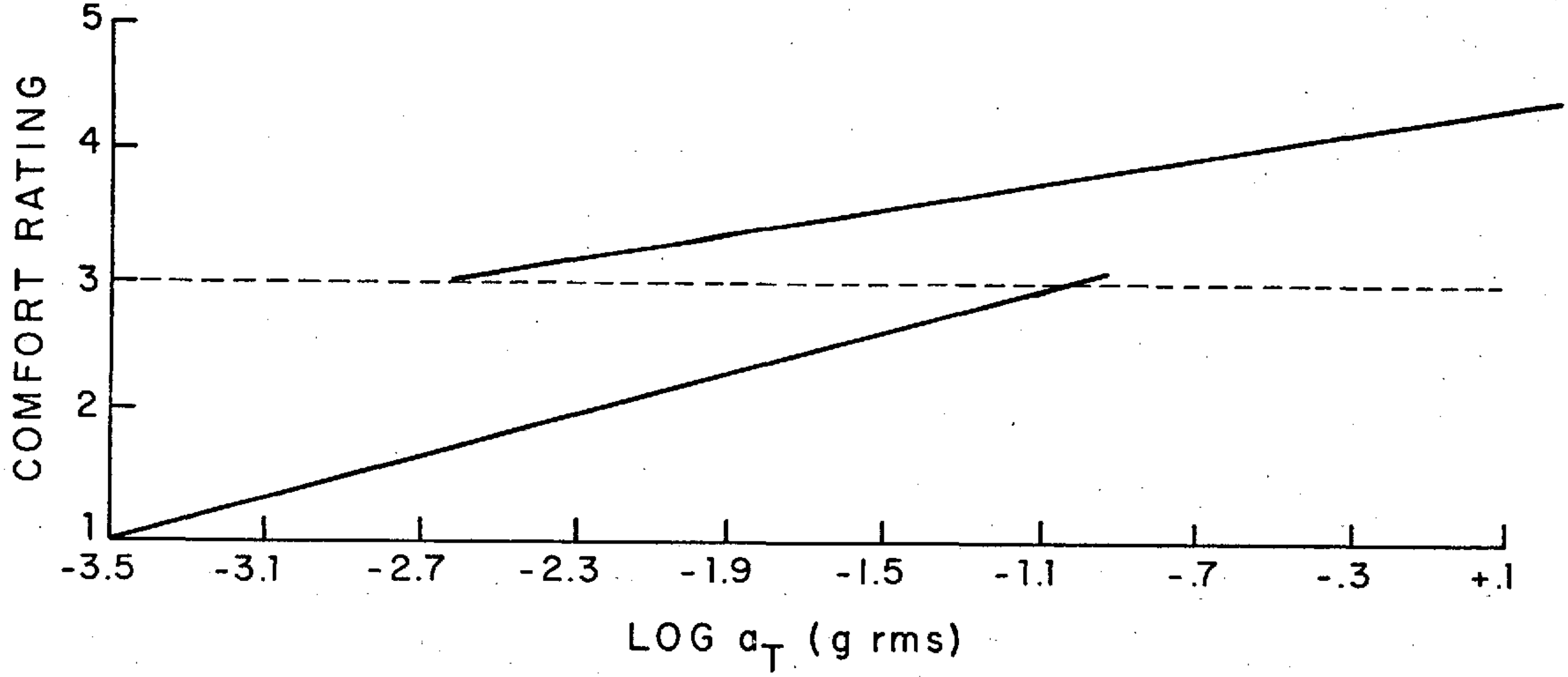

FIGURE 11. REGRESSION LINE OF COMFORT VS. LOG (TRANSVERSE ACCELERATION)

response (e.g., Weber-Fechner relation). There is one line below $C = 3$ and another above $C = 3$; these regions being separated since it is felt that above $C = 3$ the influence of biodynamics becomes important. A psychophysical-biodynamic model is being developed to explain this difference and will be published in the near future. By projection, the threshold values (corresponding to $C = 1$) can be obtained, which are as follows:

Variable	Threshold (Present Study)	Threshold (Reference 8)
a_V	.004	.002
a_T	.0003	.0008

Intuitively, these would have to be related to the sensation threshold. Comparing with the values given in reference 8, these are the correct order of magnitude.

Bank Angle Effects

A preliminary investigation of the effect of bank angle on ride comfort was carried out and the results are plotted in Figure 12. As can be seen, the mean responses have a definite correlation with the bank angle. The data were obtained at a flight speed of approximately 250 knots and indicate a maximum 25° bank for comfortable passenger operation.

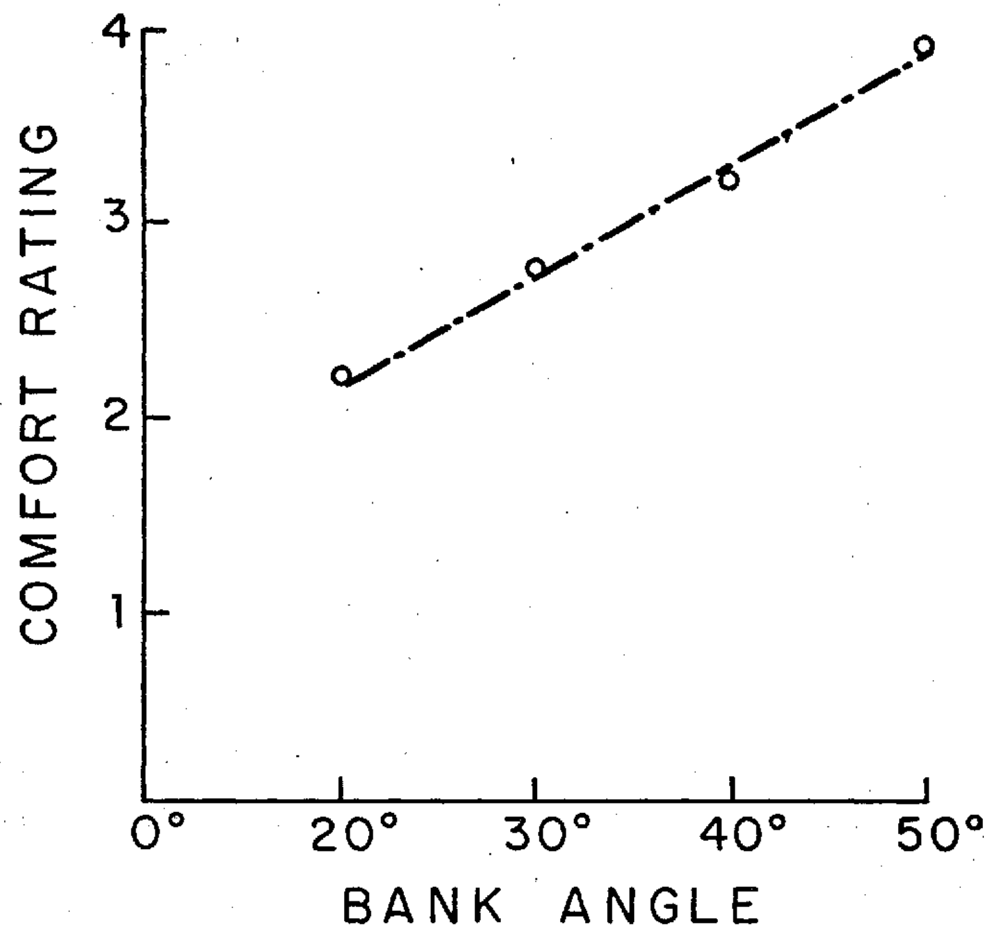

FIGURE 12. PASSENGER RESPONSES TO BANK ANGLES

CONCLUSIONS

The results of this study have yielded a model of human reaction to acceleration (rms) in the vertical and transverse directions. These indicate that transverse accelerations are worse than vertical when each is taken independently. Iso-contours are established for the combined motion regime.

It was also found that the low frequency content (i.e., <0.5 Hz) of aircraft motion is not essential for establishing ride comfort; the total rms levels are the dominant contributors. Although these findings are preliminary due to the small number of subjects, this result is promising for the use of ground-based simulators.

For coordinated turns, the recommended maximum bank angle for passenger comfort is 25° for commercial flight applications where passenger head movement cannot be prevented. This is in keeping with present commercial operations, where a 20° bank is considered standard.

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